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HELICOPTER DIVISION

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REPORT OF FIRST YEARS ACTIVITIES

NONR CONTRACT 898(00)

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Cessna Aircraft Company
Wichita, Kansas

FORM 489

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Cessna
Aircraft Company
Wichita, Kansas

HELICOPTER DIVIS N

MODEL	: REPORT NO.

REPORT OF FIRST YEAR'S ACTIVITIES

CONTRACT NONR 898(00)

This document has been reviewed in accordance wit OPNAVINST 5510.17, paragraph 5. The security classification assigned hereto is correct.

Date: 10/10

By direction of
Chief of Naval Research (Code 461)

REPORT DATE: 13 July 1953

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A. OWEN HOLLIDAY

REPORT OF FIRST YEAR'S ACTIVITIES - CONTRACT NONR 898(00)

I This report is submitted to outline the purposes and objectives of Contract NONR 898(00), the problems encountered and anticipated in carrying out the program, the methods of approach in its execution, results of the research to date, and plans for the remaining year's work.

II INTRODUCTION

Contract NONR 898(00) was activated 15 June 1952, to run for a period of two years from that date.

The objective of the project is the attainment of improved helicopter performance through the application of an aerodynamic principle, known as boundary layer control, to helicopter rotor blades.

It has long been known that the semi-stagnant layer of air immediately next to the surface of an airfoil, or lifting surface, is the source of much efficiency loss in the production of lift by such a surface. An uncontrolled, turbulent boundary layer results in both a lowered maximum lifting ability and an increase in drag of the airfoil. By removing this small layer at a certain location as it forms, as by suction through openings in the airfoil surface, the deleterious effects of this low-energy boundary air may be minimized, and the lifting surface efficiency greatly improved. By increasing the efficiency of the lifting surface, in this case the helicopter's rotor blades, the performance of the helicopter itself should benefit greatly.

Although this principle has been known for a long time, its practical application has been delayed by the formidable problem of applying it practically, in an economical manner insofar as power consumption and complexity are concerned. It is, therefore, the major objective of this program to find economical, practical methods of the application of this principle to the helicopter.

There are several possible benefits which the helicopter might derive from proper application of boundary layer control (hereinafter referred to as BLC). These are:

1. Increase in the maximum lift coefficient (and stalling angle of attack) of the rotor blade, to delay stall of the retreating blade, thus permitting higher forward speeds of the helicopter.
2. Reduction of profile drag of the rotor blade, thereby reducing the power required to produce a given lift.
3. Reduction of drag due to "shock stall" of the blades at transonic and supersonic blade speeds.
4. Contribution to rotor stability and/or control by control over the aerodynamic pitching moment of the blades through BLC.

As examples of the magnitude of the possible benefits which might be gained through the use of BLC, the following data are presented:

(a) The maximum forward speed of a typical helicopter, limited by the blade stall consideration, could be increased

by some 35 mph by delaying the retreating blade stalling angle of attack by only 5 degrees, using boundary layer control. Present wind tunnel tests have shown that the blade stalling angle can be increased by as much as 15 to 17 degrees quite easily through the use of BLC. It appears possible, therefore, that BLC could be expected to almost entirely eliminate the blade stall limitation on forward speed of some helicopters.

(b) In the hovering condition, about 35% of the engine power delivered to the rotor is used in overcoming the profile drag of the rotor blades. Many previous and current researches have shown that BLC can reduce the profile drag of an airfoil by some 50% or more. A drag reduction on the rotor blades of this magnitude would result in a total hovering power saving of 15% or more, permitting the carrying of larger payloads by the same aircraft.

It is apparent from the above that the gains in performance of the helicopter which may reasonably be expected to accrue from practical BLC application are extremely worthy of pursuit.

III METHOD OF APPROACH

It was necessary at the outset, of course, to establish a plan of action based to some extent on information available from previous researches into the subject. On the general subject of BLC much work has been done which has been directed to fixed-wing aircraft application. This work, in almost its entirety, has been done on airfoil sections unsuitable for heli-

copter use; i.e., previous research had been mostly concerned with the improvement of cambered, flapped airfoils having appreciable aerodynamic pitching moments, which cannot be tolerated in rotary wing aircraft.

An extensive basic aerodynamic investigation was therefore considered essential to the subject program. A two-dimensional wind-tunnel investigation was initiated, and is continuing, to determine optimum BLC configurations using three different airfoil sections suitable for helicopter use. Airfoil lift, drag, and pitching moment measurements are made under both steady-state and oscillatory conditions. Results of this phase of the investigation, which to date appear very encouraging, are presented in following sections of this report. Figures 1 and 2 illustrate the wind-tunnel installation used.

A parallel portion of the research program currently under way is the study of means for pumping the BLC air into or out of the rotor blade in the quantity required. This study will progress from a theoretical, analytic investigation initially to a practical pumping unit design for flight test installation in a typical helicopter.

A third important phase of the program, also being carried out concurrently with the aerodynamic work, is the experimental determination of blade structural configurations which will tolerate the necessary BLC openings in the blade surface and sub-structure. A section of a blade undergoing test is shown

in Figure 3. The immediate goal of this structural research is the design of rotor blades having the required BLC apertures and possessing the necessary structural integrity for flight test work on a typical modern helicopter, the Cessna CH-1, illustrated in Figure 4.

In addition to these phases, full-scale duct mockup measurements of airflow mixing losses through typical slots, and friction losses within ducts capable of being fitted into helicopter blades, are being made as an adjunct to the air pumping power requirements studied. A typical mockup used for this purpose is shown in Figure 5.

To date, efforts have been principally concentrated on the alleviation of rotor blade stall through increase in the maximum lift coefficient of the blade section. This has been done because of the fact that the present day helicopter is almost invariably limited in forward speed by the retreating blade stall consideration. It is generally true that as helicopters become cleaner aerodynamically and more highly powered, this already-serious limitation will become a more important detraction from their capability.

Attention is also being given to other BLC benefits at as rapid a rate as possible.

IV RESULTS TO DATE

All wind tunnel work completed to date has been on the use of single suction slots located in the forward portion of the top side of the airfoil. The objective of this wind tunnel re-

search is the accummulation of complete data which will permit establishment of design criteria for slot location and configuration, suction flow requirements, etc., for optumum BLC benefits at minimum power expenditure. Much attention has been paid, also, to seeking out any undesirable aerodynamic characteristics which might be induced by the use of BLC.

Results of this basic investigation have to date been extremely encouraging. Typical improvements to the airfoil lift characteristics are shown in Figures 6 and 7 for two of the airfoil sections under consideration. It can be seen from Figure 6 that the stalling angle of the NACA 0015 airfoil can be extended from the normal 14^{o} to approximately 31^{o}, with a corresponding large gain in maximum lift coefficient, with the use of reasonably low suction quantities. A similar gain, but of smaller proportions, is obtained from the NACA 63_2015 section, which has a much smaller leading edge radius (sharper) than the 0015 section.

Many of such tests of various slot locations have permitted the construction of the curves of Figures 8 and 9 which indicate the extent of increase of maximum lift coefficient as a function of slot location and suction flow quantity coefficient.

It has been found during the suction slot work that the major portion of maximum lift increase is obtained at the lower suction flow quantities; this, of course, is a very desirable characteristic from the power consumption standpoint.

Figure 10 is a typical cross plot of increase in maximum lift coefficient as a function of suction airflow which shows this characteristic.

As an indication of the importance of such airfoil performance improvement as has been shown in wind tunnel tests, the curve of Figure 11 shows what would be the corresponding increase in forward speed of a typical helicopter as limited by blade stall, at an altitude of 10,000'. Normal blade tip stall onset is indicated at the 13° tip angle of attack; if the stall is delayed by BLC up to an angle of only 18°, it is noted that a speed gain of 35 mph may be expected, at a reasonable BLC airflow quantity.

It has been noted during all suction-slot tests (slots located in forward portion of airfoil) that this type of BLC has negligible effect on the pitching moment coefficient of the airfoils tested. This is extremely important for helicopter application to prevent excessive vibration and control "feedback" arising from a varying, uncontrolled pitching moment on the rotor blades.

A characteristic which is undesirable, from the practical standpoint, arising from the use of BLC is that of the extreme severity and suddenness of loss of lift following the stall of an airfoil, such as a rotor blade, with BLC operating. This characteristic has been found to be almost as severe under oscillating conditions (such as a helicopter blade undergoes in forward flight) as is shown by steady state data. See Fig-

ure 12 for graphical indication of this condition.

At this time, such stall characteristics of a BLC rotor blade must be considered a factor to be investigated cautiously during flight test insofar as the total effect on the helicopter is concerned.

Drag coefficient data have been obtained on all suction slot configurations tested, both with suction on and off. However, since data on air pumping power, including losses, are not as yet complete, the profile drag as measured would be misleading if presented without inclusion of such factors, and no profile drag data are presented herein for that reason.

Considerable effort has been devoted, during the aerodynamic research conducted to date, toward the possibility of applying boundary layer control for airflow separation (stall) prevention in an intermittent manner; i.e., applying BLC only during that portion of the blade azimuth travel in which blade stall is likely to occur.

Wind tunnel data indicate this to be a definite possibility, offering a great saving in air pumping power required since the pumping unit might then be permitted to "store up suction" during the major portion of the blade travel, to be released at the predetermined critical point.

PROGRAM PLANS FOR SECOND YEAR

During the remaining 12 months of the contract term the program will be directed toward the completion of a prototype flight test BLC installation in sufficient time to permit evaluation in

flight of the effectiveness of the installation.

Specifically, this will be carried out in the following phases:

1. Continuation of basic wind tunnel research for determination of optimum BLC configurations, particularly the porous area suction type of BLC. This will consist of an extension of the work done along those lines in the past year, plus the checking of the most promising types in a higher speed wind-tunnel to obtain full-scale Reynolds Number data.

2. Continuation of experimental structural research into the effects of BLC openings on the structural integrity of practical-construction helicopter rotor blades.

3. Continuation of theoretical examination of the BLC air pumping problem, to determine the general types of pumping apparatus most promising for use in practical BLC installation on a flight test prototype helicopter, and to investigate specific off-the-shelf pumping units which may be adaptable to the job. Should this survey show no suitable production pumping unit available, design and construction of a unit for flight test prototype installation will be accomplished.

4. Installation of prototype BLC rotor blades, both small-scale and full-scale, on ground test stand for checking the apparatus prior to installation on a helicopter for flight test.

5. Installation of prototype flight test BLC rotor and pumping apparatus on the test vehicle.

6. Flight investigation of the effects of BLC on the performance and flight handling characteristics of the test helicopter.

CONCLUSION

Although a great many problems remain to be solved, no impenetrable barriers appear to stand in the way of improvement of helicopter performance through BLC. Because of the relatively short duration of the research sponsored by Contract NONR 898(00), it will not be possible completely to explore all of the many applications of BLC to helicopters; the blade stall problem has been given priority in the present research because of the pressing need for relief from the limitations imposed on helicopters by blade stall. However, basic research useful in other applications of BLC is being accomplished, with the hope of application at the earliest possible time.

During the first half of the subject contract period sufficient data have been accumulated through wind tunnel research, and analysis thereof, to indicate that extremely attractive possibilities exist in the practical application of boundary layer control to helicopter rotors.

1 – SCHEMATIC OF WIND TUNNEL INSTALLATION

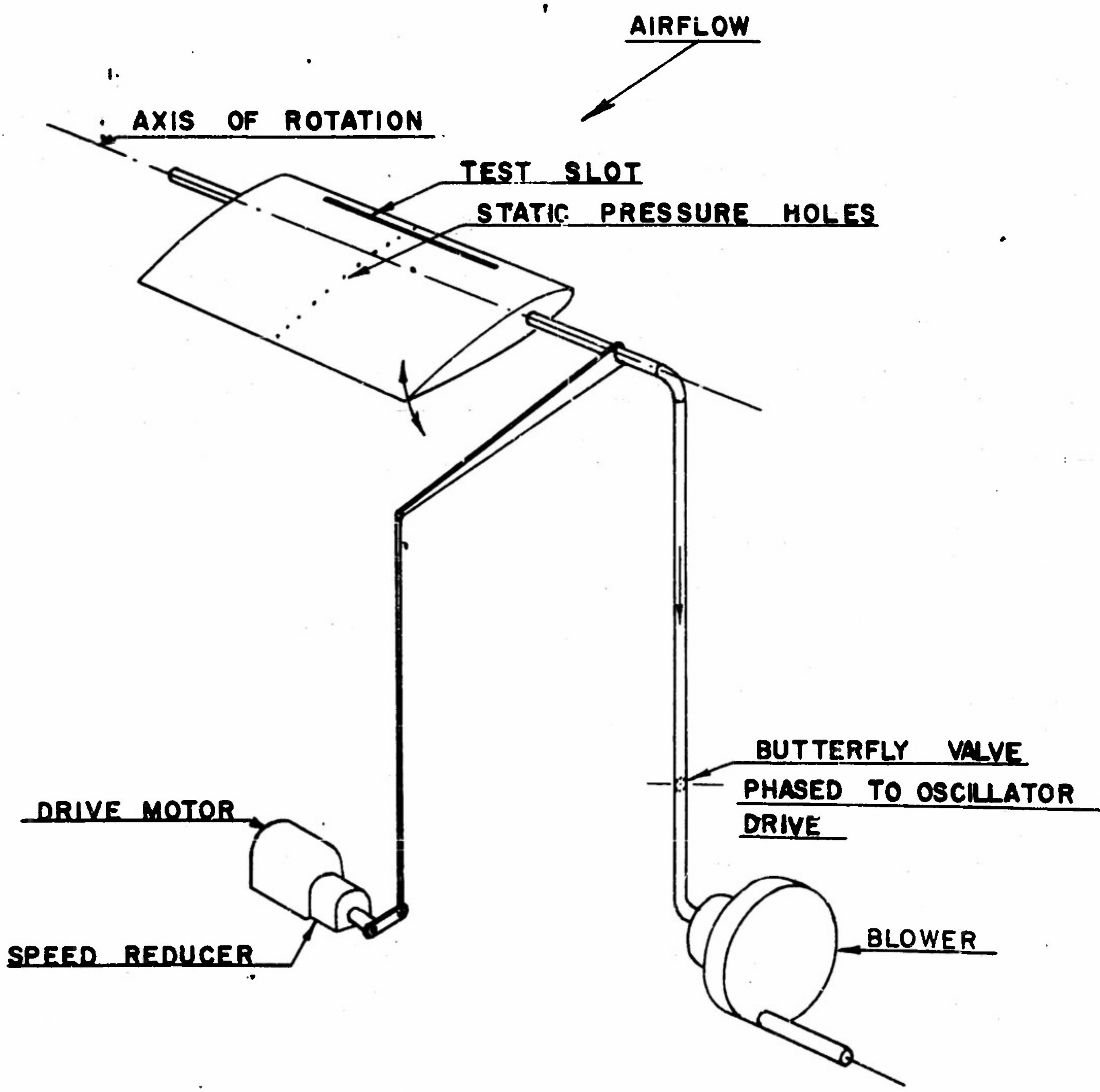

FIG. 1

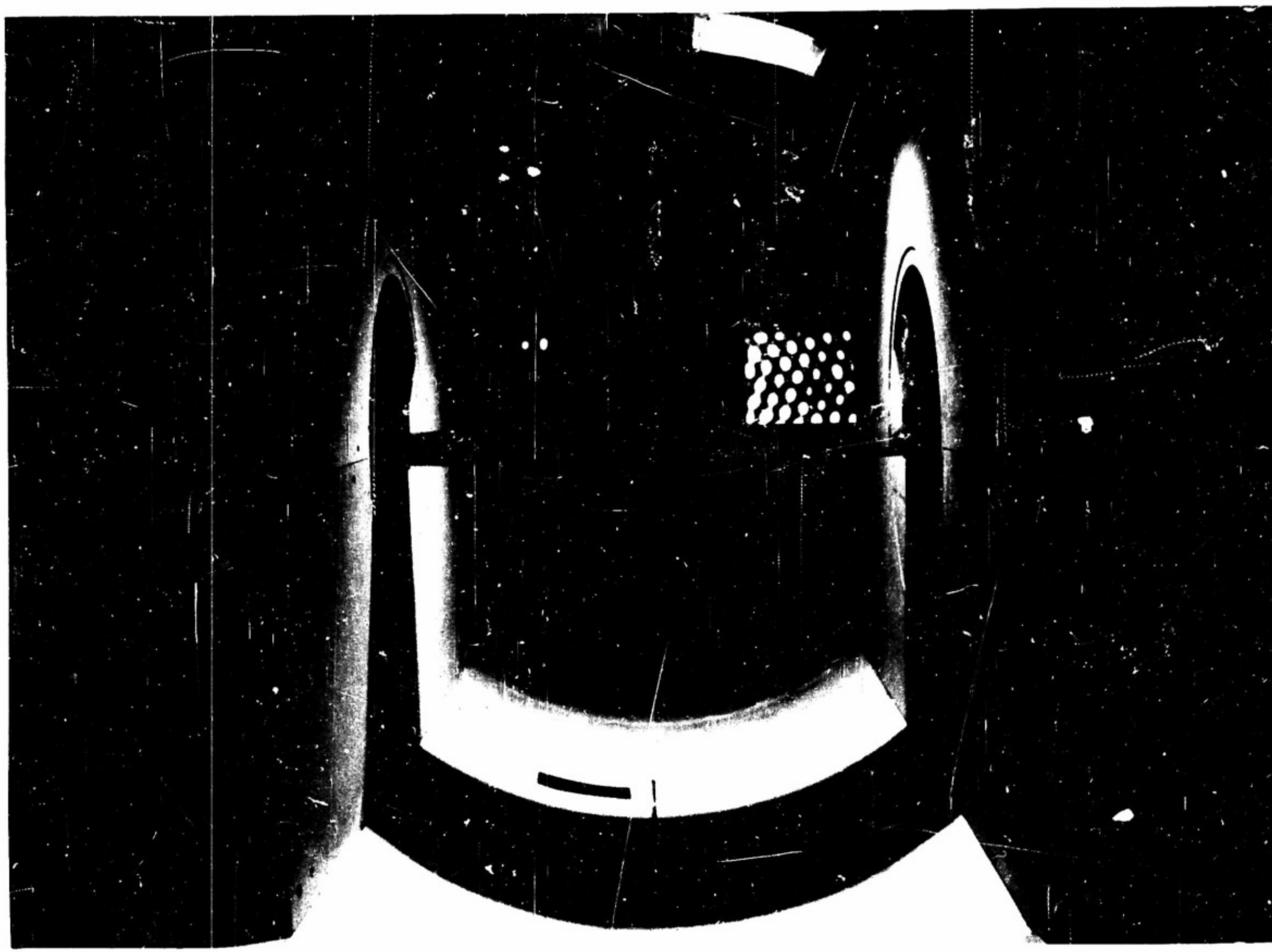

FIG. 2

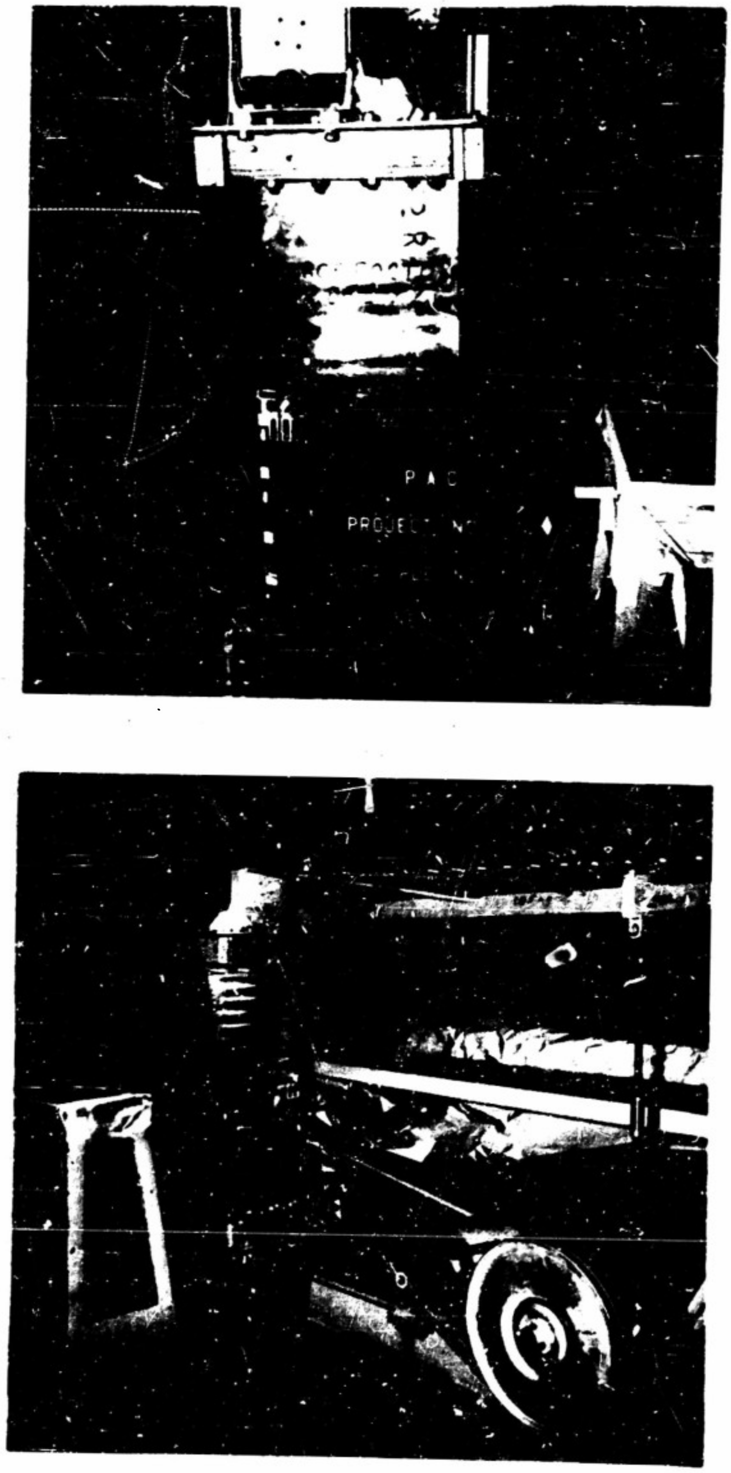

FIG. 3

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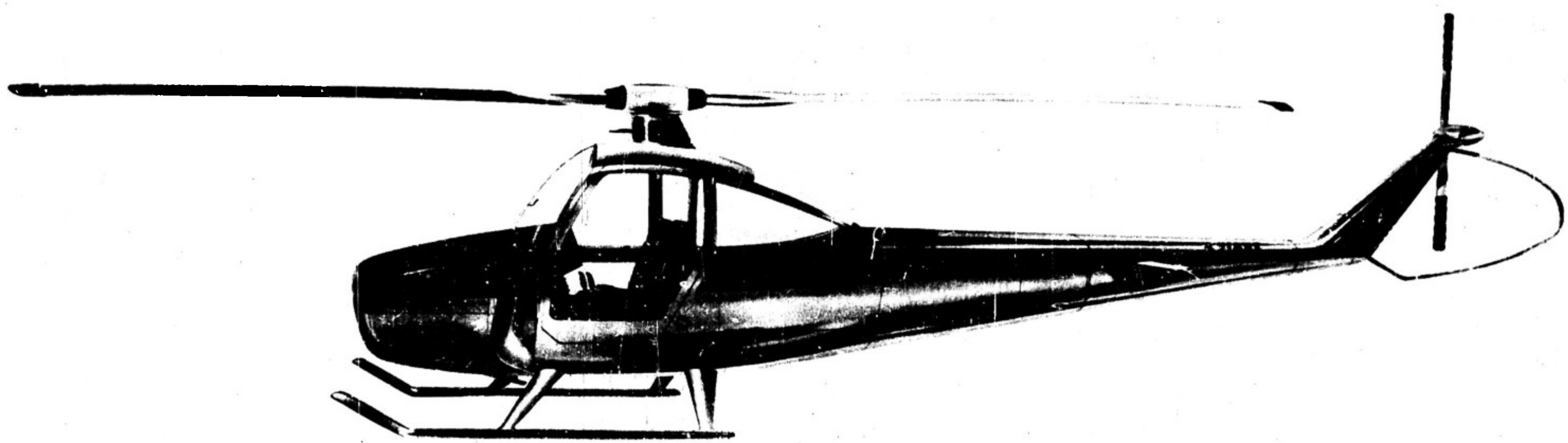


FIG. 4

FIG. 5

EFFECT OF SUCTION SLOT BOUNDARY LAYER CONTROL

ON

AIRFOIL LIFT COEFFICIENT

RESTRICTED

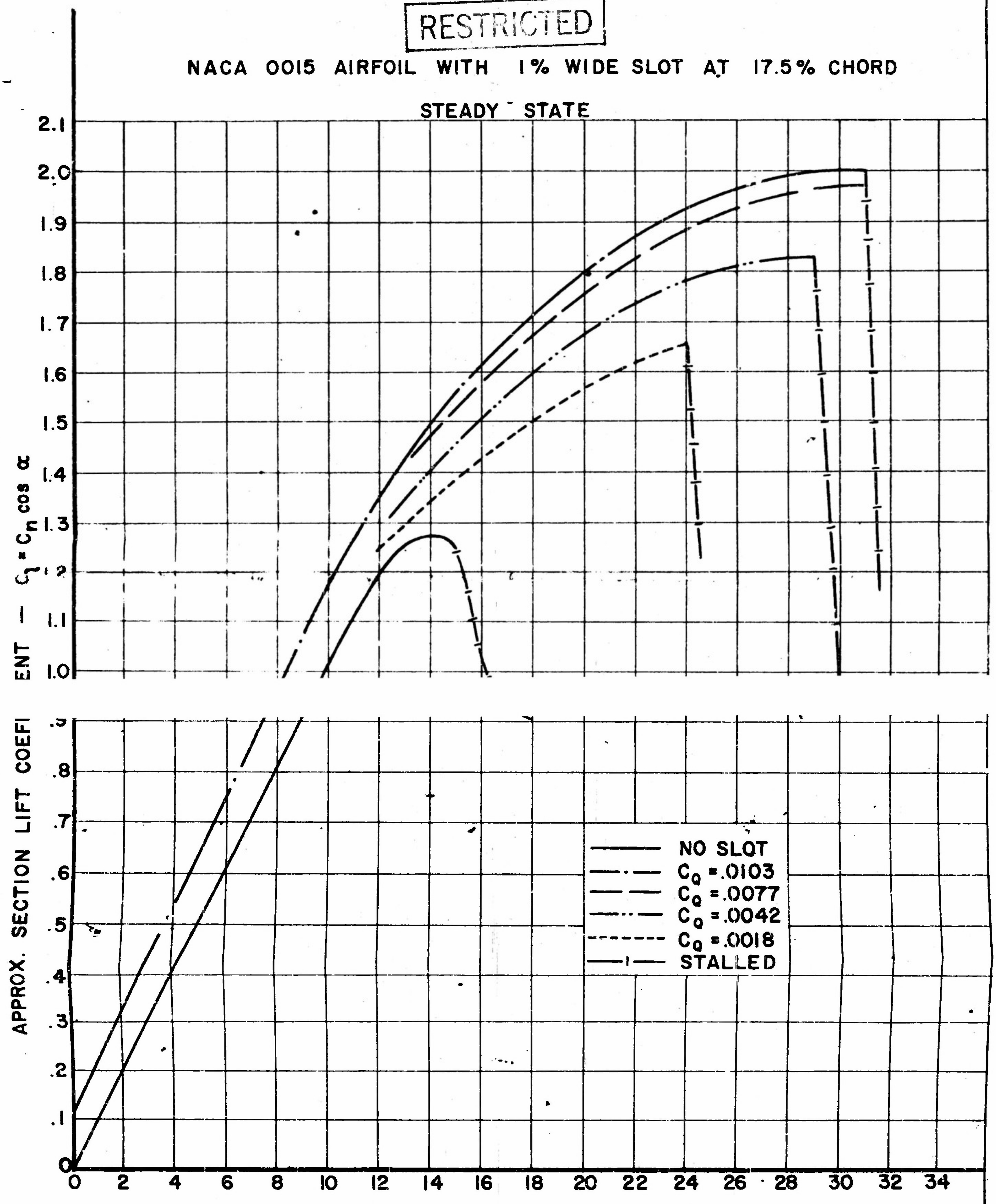


FIG. 6

EFFECT OF SUCTION SLOT BOUNDARY LAYER CONTROL

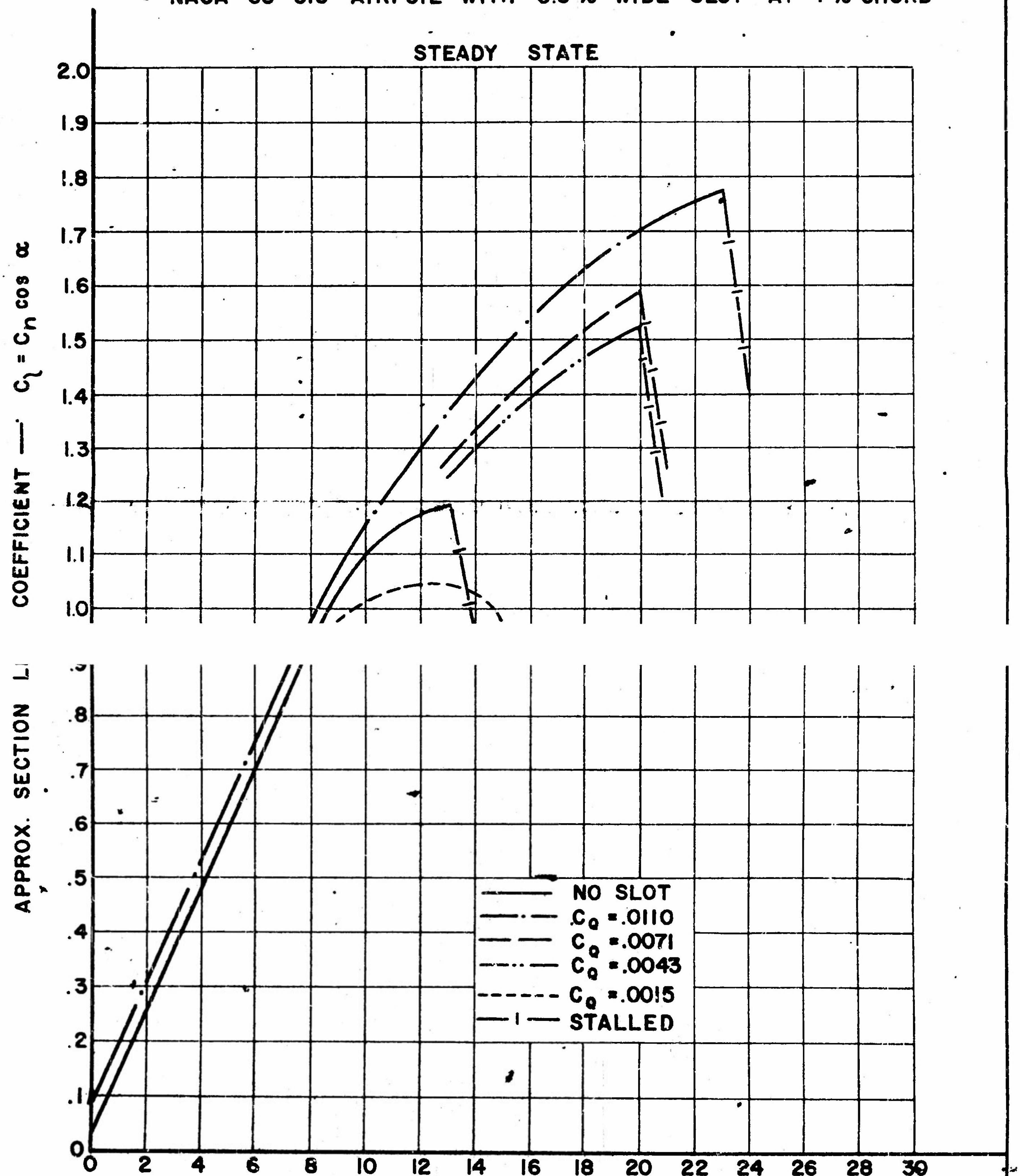
ON

AIRFOIL LIFT COEFFICIENT

RESTRICTED

NACA 63 015 AIRFOIL WITH 0.5 % WIDE SLOT AT 4 % CHORD

STEADY STATE



SECTION ANGLE OF ATTACK — DEGREES

FIG. 7

RESTRICTED

EFFECT OF SLOT LOCATION ON $\Delta C_{l_{max}}$

RESTRICTED

NACA 0015 WITH SUCTION SLOT 1% WIDE

STEADY STATE

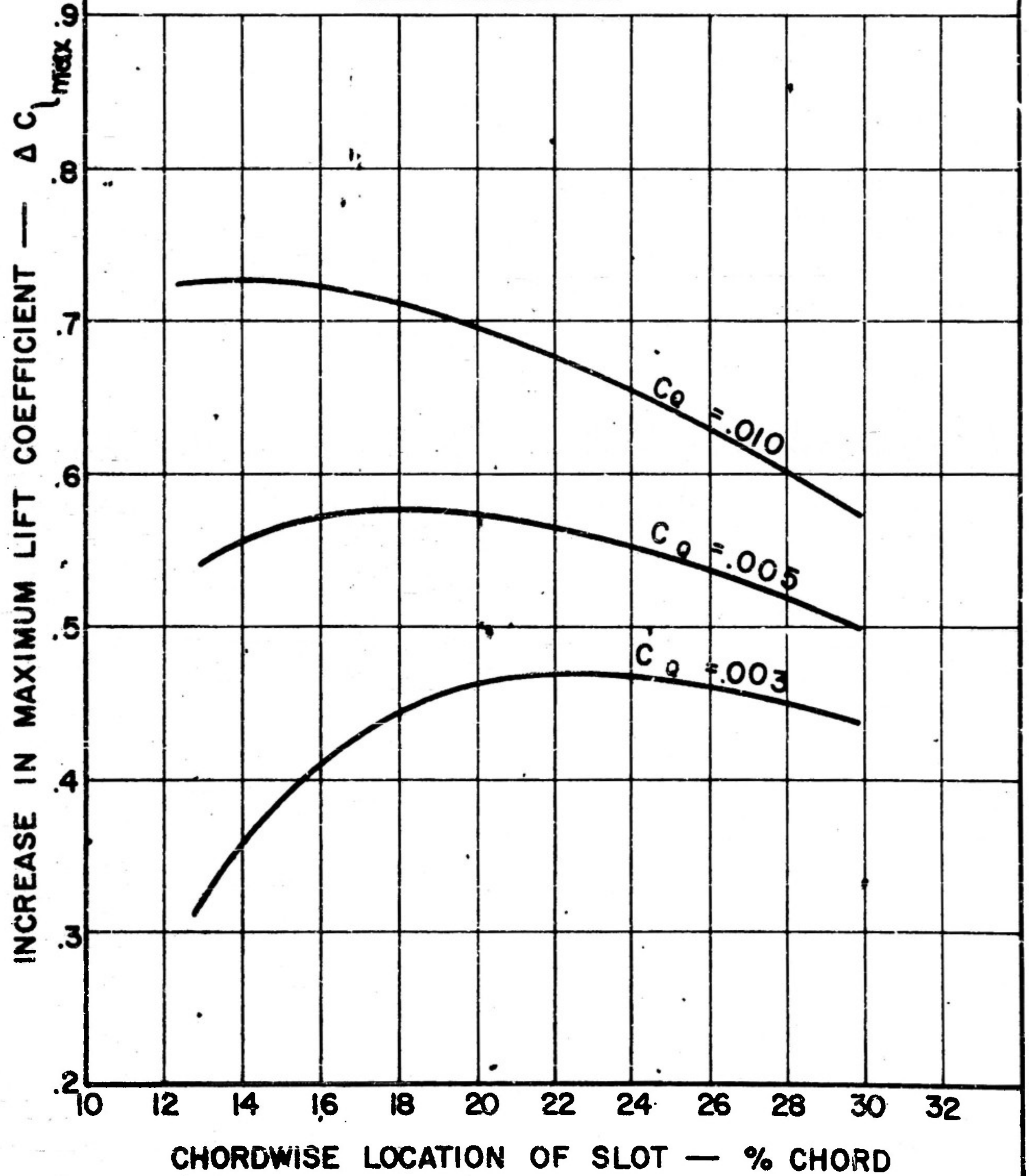
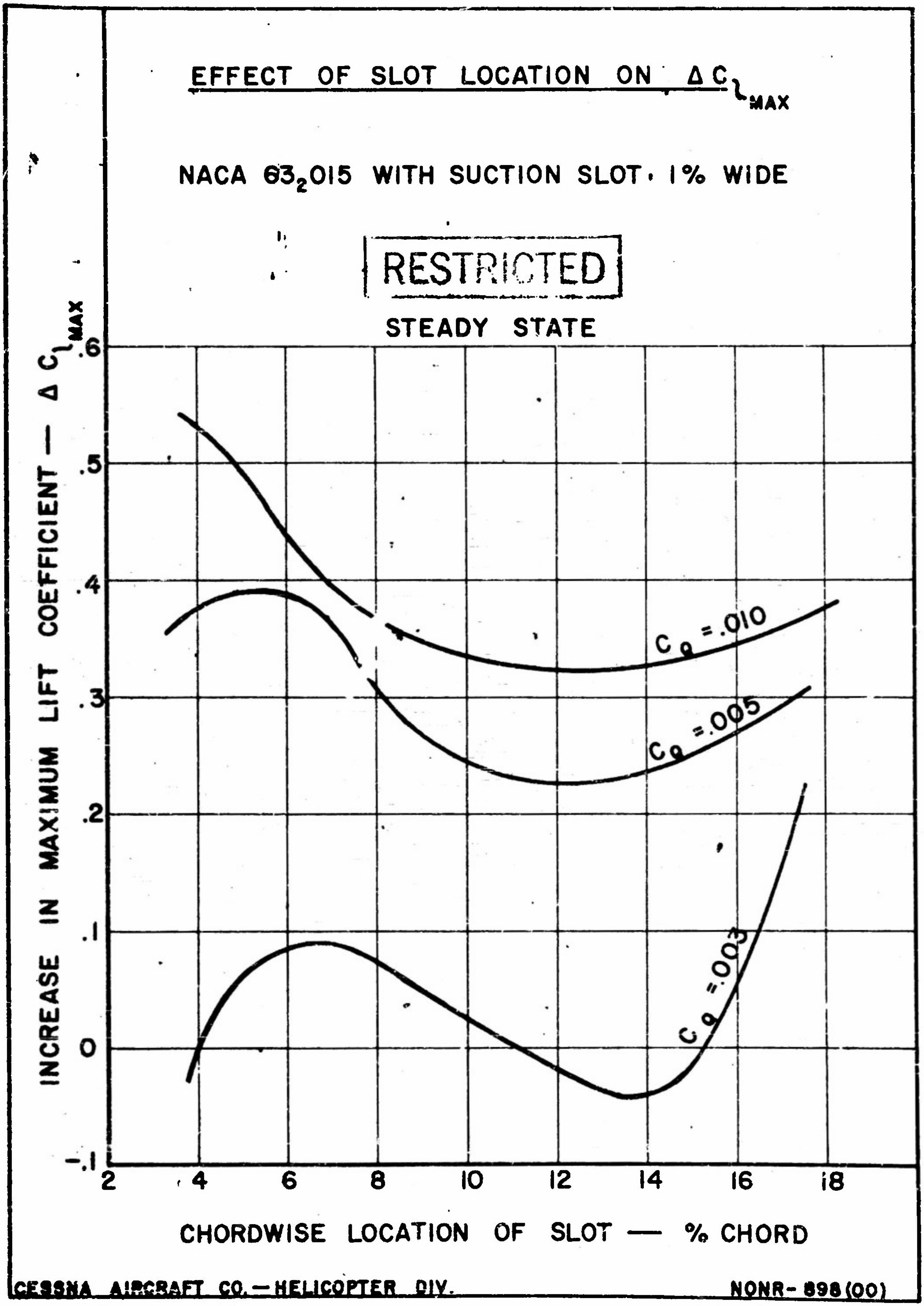


FIG. 9



EFFECT OF SLOT LOCATION ON $\Delta C_{l_{MAX}}$
NACA 63_2015 WITH SUCTION SLOT 1% WIDE
RESTRICTED
STEADY STATE
INCREASE IN MAXIMUM LIFT COEFFICIENT — $\Delta C_{l_{MAX}}$
.6
.5
.4
.3
.2
.1
0
-.1
2
4
6
8
10
12
14
16
18
$C_Q = .010$
$C_Q = .005$
$C_Q = .003$
CHORDWISE LOCATION OF SLOT — % CHORD
CESSNA AIRCRAFT CO.—HELICOPTER DIV.
NONR-898(00)

FIG. 9

INCREASE IN MAXIMUM LIFT COEFFICIENT
WITH
SLOT SUCTION FLOW COEFFICIENT

RESTRICTED

NACA 0015 WITH 1% WIDE SLOT AT 17.5% C.

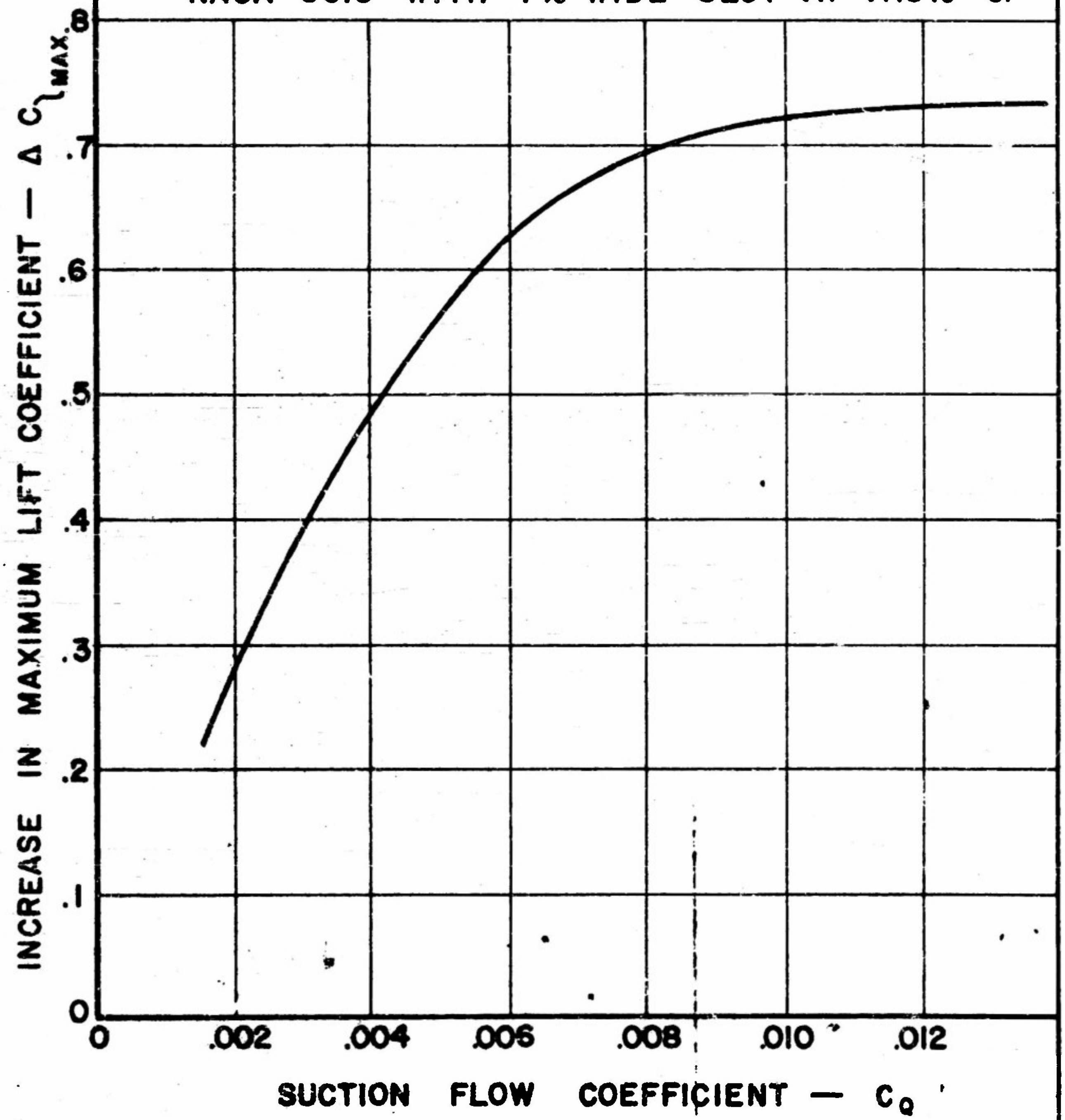


FIG. 10

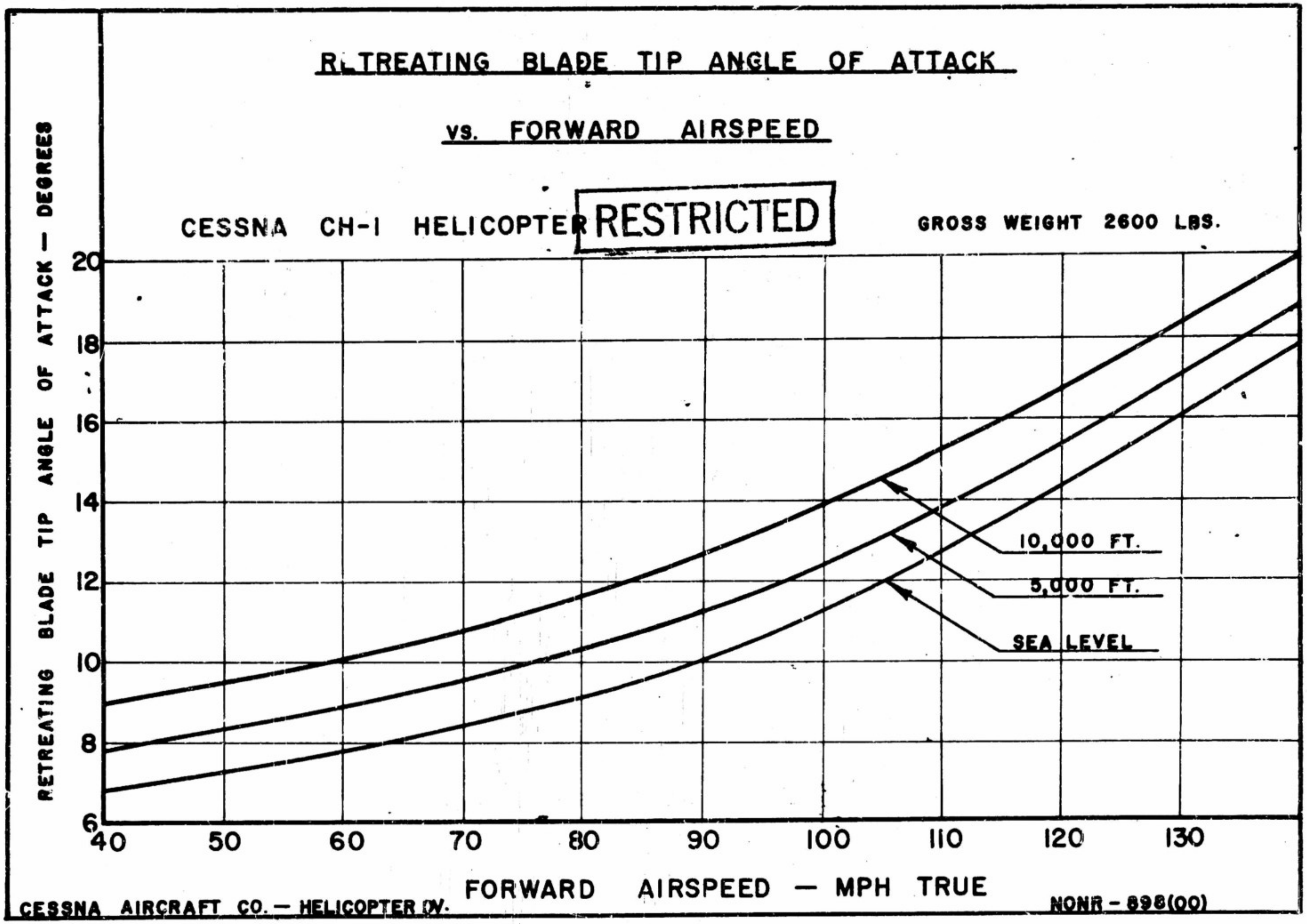

RETREATING BLADE TIP ANGLE OF ATTACK
vs. FORWARD AIRSPEED
CESSNA CH-1 HELICOPTER
RESTRICTED
GROSS WEIGHT 2600 LBS.
RETREATING BLADE TIP ANGLE OF ATTACK — DEGREES
20
18
16
14
12
10
8
6
40
50
60
70
80
90
100
110
120
130
10,000 FT.
5,000 FT.
SEA LEVEL
FORWARD AIRSPEED — MPH TRUE
CESSNA AIRCRAFT CO. — HELICOPTER DV.
NONR - 698(00)

FIG. 11

COMPARISON OF SEVERITY OF STALL OF AIRFOIL WITH SLOT SUCTION — STEADY STATE vs. OSCILLATORY